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Research Article

Pandanus Tectorius Fiber/ Rice Husk Powder as Green Reinforcement for Lightweight Composites: Evaluation of Impact Strength Properties and Thermal Stability

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ABSTRACT

Agricultural wastes such as *Pandanus tectorius* fiber (DPs) and rice husk powder (RHs) are cost-effective, low-density, biodegradable, and environmentally friendly materials. This study investigates the impact strength and thermal properties of polyester composites with varying DPs/RHs ratios. DPs treated with 20% NaOH were combined in 10%, 15%, 20%, and 30% (vol.), while RHs were varied from 5% to 10% (vol.). The results showed that increasing fiber content improved the composite's impact strength and thermal stability. The highest impact strength was achieved by sample G30/10 (30% DPs: 10% RHs) at 55.8 ± 1.89 KJ/mm^2, while the lowest was X10/5 (10% DPs: 5% RHs) at 22.23 ± 3.4 KJ/mm^2. Sample X30/5 (30% DPs: 5% RHs) exhibited the best thermal stability with only 4.47% weight loss, whereas sample G15/10 (15% DPs: 10% RHs) experienced 67% weight loss. SEM analysis revealed fiber-matrix interactions influencing impact properties. These findings suggest that DPs/RHs composites could be applied in lightweight, green thermal insulation solutions, and automotive components, promoting sustainable waste utilization.

1. Introduction

Currently, there is an increase in demand for composite products that are light, strong, heat resistant, and safe for humans in the automotive, building, medical devices, and electronic components industries [1]. Polymer composites are becoming popular due to their simplicity of production and inexpensive cost. Furthermore, the growing desire for biodegradable items is pushing the decline in synthetic materials. Fibers made from nature are being developed as a sustainable alternative to synthetic fibers owing to their longevity, abundance, cheapness, and safety for human health [2-4]. Natural fiber-based composites are now a game changer in eco-friendly material research. Various natural fibers, such as corn husk fiber, banana stem fiber, and

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hibiscus tiliaceus fiber, have been used for the reinforcement of polymer composites.

Natural fiber-based composites are a primary driving force in the development of environmentally friendly products. Natural fibers such as the husk of corn fiber, Hibiscus tiliaceus, and bamboo stem fiber have been employed to strengthen polymer composites. Pandanus tectorius leaves could be a source of fiber. Although this fiber has a lot of potential, its usage as a composite reinforcing material has received little attention, despite the fact that various studies have shown its exceptional physical and mechanical qualities. Pandanus tectorius is a member of the Pandanaceae family [1,5]. This plant can be found along the South and East Asian coasts such as Indonesia, Malaysia, India, and Thailand. Pandanus Tectorius leaves are typically 90-150 cm long and 5-7 cm wide. These leaves were previously widely used in crafts and furniture. Several studies have examined the physical and mechanical properties of Pandanus fiber, including fiber extraction methods with alkali treatment and bleaching that increase cellulose content and thermal stability [1,5]. However, research on the combination of Pandanus fiber with rice husk powder filler in polymer composites is still very limited.

The potential of fiber produced from Pandanus Amaryllifolius using a water-retting extraction procedure has been studied by Diyana et al. [1]. They found that the fiber's cellulose, hemicellulose, and lignin contents were, respectively, 48.79%, 19.95%, and 18.64%. A tensile strength of 45.61 ± 16.09 MPa has been reported for fibers having a diameter of 368.57 ± 50.47 μm, and these fibers may be used as reinforcements for bio-based polymers. Through the use of acid hydrolysis, bleaching, and alkalization techniques, Through the use of acid hydrolysis, bleaching, and alkalization techniques, Syafri et al. [6] have been able to recover the fiber content of Pandanus tectorius. They stated that following chemical treatment, the fibers broke down into cellulose fibrils that ranged in diameter from 2 to 20 μm. Additionally, they stated that the thermal stability of the treated fiber was superior to that of raw fiber that the cellulose content had grown by 90.5% and the hemicellulose percentage had dropped by 89.6%. In addition, a number of researchers have already created pandanus fiber for use in composite reinforcement, and the material's mechanical and physical characteristics have been documented. Afolabi et al. [7] used a combination of alkaline bleaching and sodium chlorite (NaClO2) for their alkaline treatment, which resulted in the extraction of leaf fiber from Pandanus tectorius. According to their findings, the extraction method increased the amount of cellulose in leaves by 87% to 73% when treated for 120 minutes with 10% weight percent NaOH. The researchers also observed that the tensile strength of epoxy composites reinforced with cellulose fiber and alkali-bleach mixture was found to be 40% greater at 35 2.8 MPa than that of untreated cellulose fiber composites. Sheltami et al. [8] extracted cellulose nanocrystals from Pandanus tectorius leaves by bleaching and treating them with an alkali. According to what they said, the extracted cellulose had significant amounts of hemicellulose and lignin removed. It was discovered that the sizes of the separated cellulose and cellulose nanocrystals were respectively 5–80 μm and 5–25 nm. It was observed that, in comparison to the raw material, the leaves' thermal stability increased at different phases of refinement. In an additional investigation, Sari et al. [9] examined pandan leaf fiber treated with dicumyl peroxide (DCP) for enhancing polyethylene composites. They stated that a tensile strength of 81.7±10.60 MPa was the ideal value for polyethylene composites treated with 4% DCP. Weerappuliarachchi et al. [10] used alkali treatment and bleaching to extract cellulose from Pandanus ceylanicus plant leaves, whereas sulfuric acid treatment was used to remove microcrystalline cellulose (CMC). They reported on globular CMC crystals with less than one micrometer as the typical diameter. It is known that adding CMC to nylon 6,10 increases water absorption while decreasing water retention time. In the past few years, a number of other researchers have noted that natural fibers like cornhusk fiber, kenaf, and jute are also known to form polymer composites with rather high tensile strengths [11,12,13].

One of the primary agricultural wastes produced in rice-growing nations is rice husk (RH). Notwithstanding its wide range of uses, its advantages and financial impact have not received enough attention. When rice is milled and hulled to produce smooth, white grains free of bran and husks, a byproduct known as RH is produced [14,15,16]. Rice husk, one of the most common agricultural wastes in rice-producing countries, is a low-cost, renewable, and easily reachable material, however, its potential as a composite filler has received little attention. Several earlier investigations have shown that rice husk powder improves composite mechanical characteristics and erosion resistance [14-19]. However, rice husk has limitations including low mechanical strength and low dimensional stability when moisture [9,20]. The addition of pandan fiber in composites may solve these issues by improving dimensional stability, resistance to moisture, and mechanical strength. Composites reinforced with 40%–70% rice husk content have been reported

to exhibit flexural and tensile strengths of 2.73 MPa–0.11 MPa MPa [17]. In glass-epoxy composites, adding 5–15% rice husk is known to improve the composite's hardness, tensile modulus, impact energy, and erosion resistance while decreasing its tensile and flexural strengths [18]. Hemnath et al. [19] also published a recent study on the addition of 10% (wt) rice husk powder filler to bagasse fiber-reinforced polyester composites. They concluded that for all volume fraction variations of bagasse fiber with rice husk powder filler, the tensile strength of the composite sample decreased and that the filler was only effective in increasing the toughness of the composite. This is due to the presence of too much filler (10% wt.), which results in the adhesion of the polyester-bagasse fiber matrix inside the composite, lowering tensile and flexural stress. The main drawbacks of using rice husk as a composite filler material are its low mechanical strength, brittleness when damp, and poor dimensional stability [9,20]. These drawbacks can be addressed by using Pandanus tectorius fibers, which boost the composite's dimensional stability, moisture resistance, and mechanical strength [7,8,9]. However, a number of studies have shown that fillers in different polymer composite materials can be made from rice husk powder and Pandanus tectorius fiber. But as far as we are aware, no research has combined the use of pandanus fiber with rice husk powder fillers for the reinforcement of polyester composites, with a focus on the material's mechanical, thermal, and physiochemical properties.

Therefore, the purpose of this study is to explore the impact strength and thermal parameters of polyester composites reinforced with pandan fiber and rice husk powder filler. Pandan fiber content was changed to 10%, 15%, 20%, and 30% (vol.) respectively, with rice husk powder employed as a filler at 5% and 10% (vol.). This study is expected to shed more light on the possible usage of pandan fiber and rice husk powder composites as an alternative to wood in construction applications.

2. Materials and Methods

2.1. Materials

The leaves of *Pandanus tectorius* were collected in East Lombok, West Nusa Tenggara, Indonesia. Rice husk (RH) was obtained from Pagesangan, Lombok, Indonesia (Fig. 1). Rice husk was milled in a milling machine and sieved through a 40 Mesh sieve (0.4 mm). The characteristics of rice husk powder (RHs) are shown in Table 1. While, the matrix is made of polyester resin, and its specifications are shown in Table 2.

Fig. 1. The process of sifting rice husk powder (RHs)

Table 1. The chemical content of rice husk powder (RHs) [20]

The chemical content of rhs	(%)
Carbon	1.33
Hydrogen	1.54
Oxygen	33.64
Silica	16.98

Table 2. Mechanical Properties of Unsaturated Polyester Resin [16].

Mechanical properties	Unit	Values
Tensile Strength	MPa	90
Compressive Strength	MPa	55
Elastic modulus	GPa	3.23
Density	g/cm^3	1.35

2.2. Extraction of Fibers

The process of extracting Pandanus tectorius leaf fiber (DPs) is shown in Figure 2. First, pandan leaves are selected from older leaves and carefully cleaned with plain water to clear any particles and dirt that may have adhered to the leaves (Fig. 2a). After 5 days in water (Fig. 2b), the fibers on the leaves were removed with a wooden comb (Fig. 2c). The fiber bundles were then aerated until the water content was less than 10% by weight (Fig. 2d) before being stored in airtight containers as fiber raw (DPs raw).

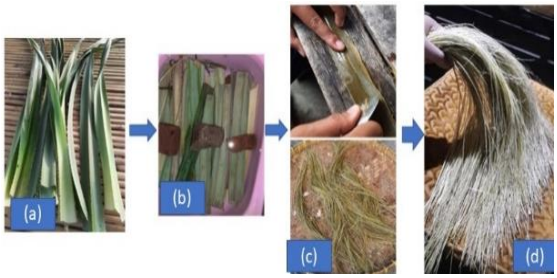

Fig. 2. The extraction process is (a) *Pandanus tectorius* leaf selection, (b) soaking *Pandanus tectorius* leaves in water, (c) sweeping the fibers, and (d) drying *Pandanus tectorius* leaf fibers (DPs).

2.3. Alkali Treatment of DPs

The dried Pandanus tectorius leaf fibers (DPs) were then immersed in a 20% NaOH solution for 4 hours (shown in Fig. 3). The use of alkali is one method of reducing the surface tension of the fiber; in addition to reducing the surface tension of the alkaline treatment, it also aids in the removal of impurities on the fiber's surface. The fibers are rinsed and air-dried before being stored in an airtight container.

Fig. 3. The process of treating *Pandanus tectorius* leaf fiber.

The chemical makeup of the raw and processed DPs, comprising cellulose, hemicellulose, and lignin, was also ascertained by chemical analysis. NFT 12-008 was followed in the measurement of the cellulose and hemicellulose composition of the Journal Pre-proof utilizing Kushner and Hoffer's procedure [21]. The lignin content was measured by modifying Klason's technique in accordance with APPITA P11s-78 [22]. Table 3 shows the precise chemical reaction between raw fibers and treated DPs.

Table 3. Chemical content of raw and treated DPs

Samples	Cellulose (%)	Hemicellulose	Lignin
DPs raw	37.3 ± 0.6	34.4 ± 0.2	22.6 ± 0.8
DPs treated NaOH	57.5 ± 0.8	15.5 ± 0.1	24 ± 0.2

2.4. Fabrication of Composites

In order to achieve the best possible balance between strength and material qualities and to make mixing and composite manufacture more efficient, the treated DPs were weighed in multiples of 10%, 15%, 20%, and 30% (vol. fraction) and RHs was changed from 5% to 10% (% vol.) [23]. Polyester resin, rice husk, and catalyst (3% (% vol.) of total resin) were combined to make a dough, which was then poured into a PDs-filled mold. Table 4 displays the composite component ratios. The composites were fabricated by utilizing a silicon rubber composite mold and the composite manufacturing technique based on the component ratio.

Table 4. The ratio of each component of the polyester composite

Samples Code	*Pandanus tectorius* fiber (DPs) (% Vol.)	Rice husk powder (RHs) (% Vol.)
X10/5	10%	5%
X15/5	15%	
X20/5	20%	
X30/5	30%	
G10/10	10%	10%
G15/10	15%	
G20/10	20%	
G30/10	30%	

2.5. Characterization

2.5.1. Impact strength

The Charpy impact test was performed on a Model IT-30 impact testing machine to investigate the impact strength of the composites. The test specimen (notched) was prepared in accordance with the ASTM D-256 standard. Using the pendulum drop method, impact loads were applied to the specimen until it cracked. The total number of samples for the impact test was 24, with each parameter being repeated three times. Fig. 4 depicts the test sample, the impact test process, and the sample fracture impact test results.

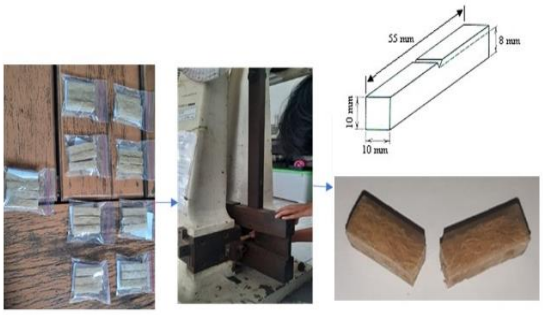

Fig. 4. The impact test process

2.5.2. Thermogravimetric Analysis (TGA)

Mettler-Toledo and 70 µL aluminum oxide pans were used for all measurements. Both gases were measured under a nitrogen (quality 5.0) atmosphere with a gas flow rate of 50 mL/min. In the TGA instrument, samples were dried at 200 °C for 10 minutes in an inert atmosphere

before being measured. A heating phase (first segment) in a nitrogen atmosphere from 25 to 500 °C was followed by a cooling phase (second segment) in nitrogen to 200 oC and a subsequent heating phase.

2.5.3. Differential Scanning Calorimetry (DSC)

An aluminum crucible containing 10 ± 2 mg of homogenized sample was weighed in preparation for DSC measurements. The lids were placed on the crucibles, and they were punctured. A Mettler Toledo 823e differential scanning calorimeter that had been argon-purged was used for DSC tests. Three cycles—heating, cooling, and heating—with a heating rate of 10 K/min were applied as part of the temperature program between 25 and 500 °C. In addition, a 3-minute isothermal phase was included in between each cycle. As a result, one analysis took fifty-five minutes.

2.5.4. Scanning Electronic Microscopy (SEM)

Using a Quanta FEG 250 Fei model microscope with an Everhart-Thornley secondary electron detector running at a 5 kV acclimation voltage, a morphological study of the composites' surface was carried out by scanning electron microscopy (SEM). The samples were sputtered with gold using a Leica ACE600 sputtering apparatus in preparation for the SEM visualization. Using a Hitachi scanning electron microscope (model TM3000), the fracture surfaces of the composites were examined. A voltage of 20 kV was assigned to the electron beam. A cathodic sputter model ACE600 (Leica, Germany) was used to coat the samples with a thin layer of gold for a duration of 30 minutes.

3. Results and Discussions

3.1. Impact Strength Analysis

The impact strength values of the DPs/RHs composites are shown in Fig. 5. The G30/10 sample had the maximum impact strength (55.8 ± 1.89 KJ/mm^2), whereas X10/5 had the lowest (22.23 ± 3.4 KJ/mm^2). These findings show that the composite's strength to impact forces increases proportionately when DPs are added in higher concentrations. The composite's resistance to deformation and breaking is enhanced by the Pandanus tectorius fibers, which serve as a barrier. In addition, as the fiber content increases, the impact load distribution in the composite becomes more uniform. This is because there are more fibers to disperse the load and withstand the impact force, which lowers the concentration of stress at specific locations in the composite. This lowers the possibility of local failure, which could weaken the composite's overall strength. 3.2 Tensile strength analysis

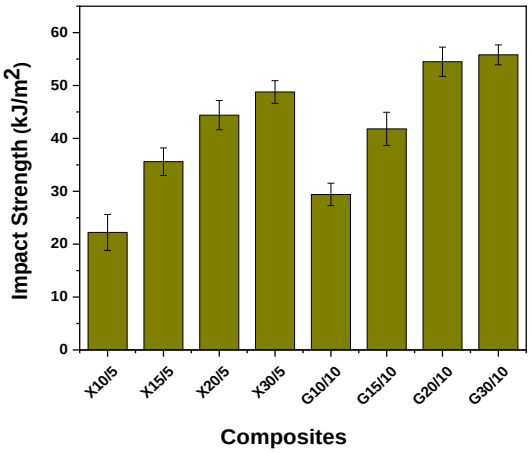

Fig. 5. Impact strength of the composite of DPs/RHs

Additionally, the strength increase demonstrates that concentrations of 5% and 10% rice husk are considered to be adequate to offer notable reinforcement without damaging the composite's overall performance. By distributing the load imparted to the composite, this RH filler works well. Decreasing the concentration of the load on a specific region boosts the composite's resistance to impact damage. Also, the interfacial interaction between the Pandanus tectorius fiber, filler, and resin matrix has increased as a result of the RH filler's presence in the composite. The interfacial strength between the fibers and the resin and the filler itself may rise as a result, leading to a denser and more cohesive composite structure and an overall increase in the composite's strength against impact. On the other hand, poor impact strength results from low fiber content, resin damage, and debonded fibers [24].

3.2. Thermogravimetry Analysis (TGA)

Figures 6a and 6b display the TGA of DPs-reinforced composites with filler RHs of 5% and 10%, respectively. The weight loss of the composite as temperature rises is reported by TGA. The thermal stability increases with the breakdown temperature. The weight of the composite decreased as a result of the cellulose, hemicellulose, and lignin components breaking down during heating. As can be seen in Figure 6a, the mass loss for DP composite samples with 5% filler for samples X10/5, X15/5, X20/5, and X30/5 is 3.61%, 4.28%, 3.10%, and 3.81%, respectively, at each percentage point. In contrast, the mass loss for DP composite samples with 10% filler for samples G10/10, G15/10, G20/10, and G30/10 is 5.51%, 4.3%, 7.09%, and 9.35%, respectively. Due to the water in it evaporating, the composite dehydrates during

the first stage of mass reduction. In DP composites with 5% filler, the mass reduction in the first stage is evident before the temperature reaches 200 °C, yielding a mass reduction of less than 5%, but in DP composites with 10% filler, the mass reduction is greater than 5%. The composite's mass is decreased to more than 60% of its total mass during the second stage of mass reduction, which starts between 200 and 420 degrees Celsius. The breaking of thermal chemical bonds occurs at this temperature, causing carbon char to form during this peak decomposition process. At temperatures between 400 °C and 500 °C, there is still a steady mass decline following the decrease in peak mass that takes place in the third stage of mass loss. The third stage's mass decrease was 3.85%, 6.15%, 7.18%, and 6.6% for samples X10/5, X15/5, X20/5, G20/10, and G30/10. With this decomposition process, the charcoal oxidizes slowly over 400°C, which causes the mass to drop and leaves the least amount of residue [25].

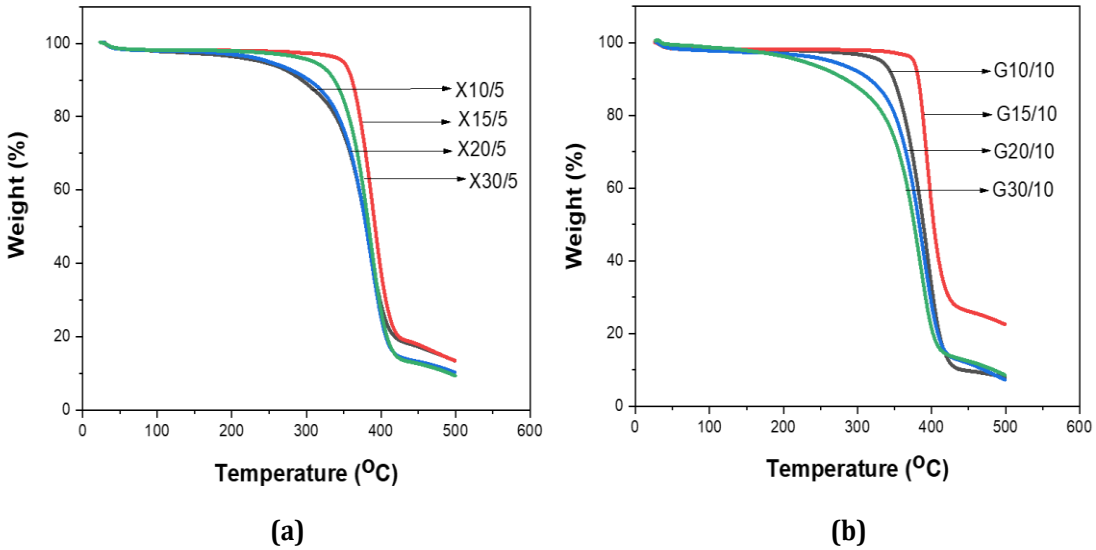

Fig. 6. Thermogravimetric analysis (TGA), (a) DP composites with 5% RHs, and (b) DP composites with 10% RHs.

From Figs. 6a and 6b show that the best percentage for thermal resistance to decomposition is X30/5 of 4.47%, and G15/10 of 67%, at which percentage the composite undergoes the least decomposition in the third stage, resulting in the more widely residue. This is due to the bonding that occurs in the composite, which is very strong and has a matrix interface with dense reinforcement compared to the bonds and interfaces in other composites; in other words, the composite with this percentage has the best thermal resistance.

3.3. DSC Analysis

Because the heat flow in the sample is higher than the heat flow in the reference DSC instrument, Fig. 7a illustrates that the composite DPs with 10% and 5% RHs are monotone and upward. This suggests that the sample is exothermic, meaning it releases heat into the surroundings [19,24,25]. Samples X10/5, X15/5, X20/5, and X30/5 respectively, have heat flows of 25.26 mJ/s, 31.08 mJ/s, 44.48 mJ/s, and 49.45 mJ/s, respectively, as shown in Fig. 7a. The sample composite then reaches the first endothermic phase's peak and melts as a result of heat absorption at 383 °C, 386 °C, 382 °C, and 381 °C, respectively, with a heat-flow of 16.63 mJ/s, 386 mJ/s, 382 mJ/s, and 381 mJ/s respectively. The second endothermic peak for samples X10/5 and X20/5, respectively, appears at 411°C and 423°C, with a heat flow of 34.74 mJ/s and 95.18 mJ/s. The third endothermic peak occurred at 419 °C with a heat flow of 56.1 mJ/s, and the third exothermic peak was discovered in sample X10/5 at 417 °C with a heat flow of 56.3 mJ/s. Without any more heat absorption, the composite rises toward the exothermic or endothermic, which is caused by oxidation leading to disintegration and a change in the composite's structure.

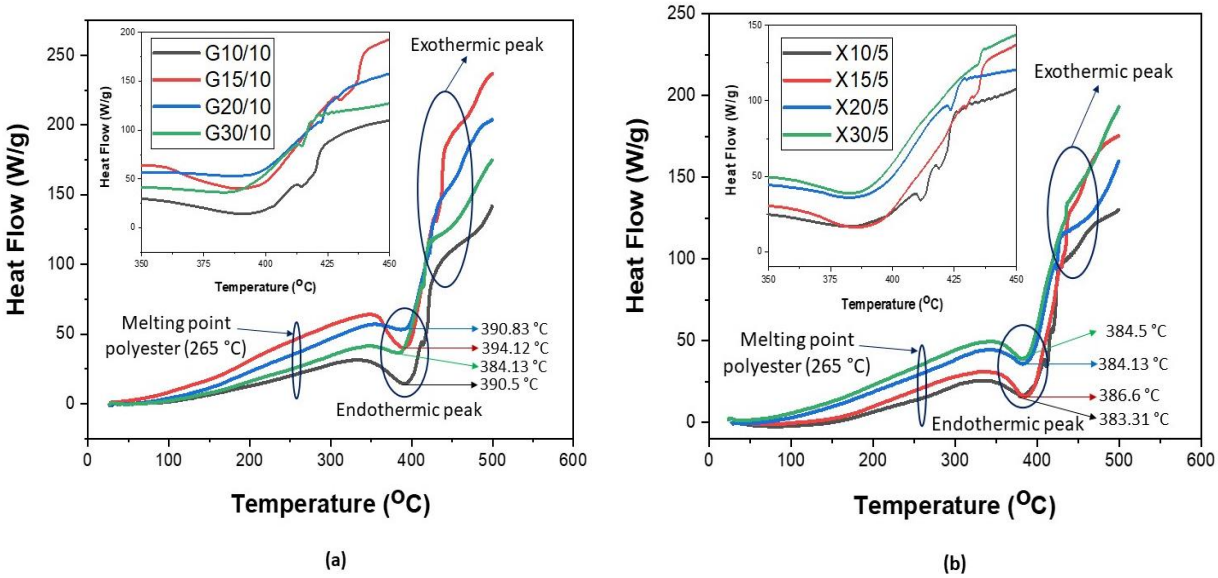

Fig. 7. Heat-flow and temperature of DP composites with rice husk powder (a) 5%, and (b). 10%

Figure 7b further demonstrates that while some composites do not have multiple melting point peaks in the exothermic phase or crystallization points in the endothermic phase, they all share the trait of being monotonous towards the exothermic due to a composite's heat flow being higher than that of the reference sample. With a heat flow of 31.26 mJ/s, 64.08 mJ/s, 57.02 mJ/s, and 41.44 mJ/s, respectively, the samples G10/10, G15/10, G20/10, and G30/10 are at the peak of the first exothermic phase at 331 °C, 347 °C, 354 °C, and 346 °C. At 391 °C, 388 °C, 386 °C, and 383 °C, respectively, the composite sample absorbs heat with a heat flow of 14.55 mJ/s, 40.1 mJ/s, 53.21 mJ/s, and 36.29 mJ/s. This causes the composite sample to enter the peak of the first endothermic phase and melt. In the case of samples G10/10 and G15/10, the second endothermic peak is recorded at 414°C, while sample G30/10 reaches 413°C. The corresponding heat-flow values are 42.95 mJ/s, 131.81 mJ/s, and 84.45 mJ/s. Lastly, with a heat flow of 25.26 mJ/s and 31.26 mJ/s at the initial melting point, samples X10/5 and G10/10 have the lowest heat flow compared to the other samples. This suggests that in the initial phases of the melting process, the absorption or transmission of heat is comparatively modest for both kinds of composites. This suggests that substantial quantities of polyester utilized in composite materials do not effectively transmit heat. Particularly for computer or smartphone applications, low heat flow rate materials are preferred to regulate the melting process or avoid material failure from high heat early in the process.

Although this study found that pandan fiber composites loaded with RHs improved their impact strength and thermal stability, certain limitations must be acknowledged. The uneven distribution of RHs in the composite matrix can result in voids between fibers and the matrix. These voids can impede load transfer and lower the composite's impact strength. Furthermore, while the addition of DPs enhances mechanical qualities, a larger RH concentration (10%) can reduce tensile and flexural strength, as demonstrated in prior research. Another drawback is the composite's brittle character with increased fiber concentration, which may influence the material's resistance to breaking or damage when subjected to recurrent loads. Furthermore, this study is limited to the measurement of impact and thermal characteristics, with no additional investigation of the composite's resilience to environmental conditions that involve humidity or UV exposure, which are critical in long-term applications, particularly in the construction sector. Further research is required to maximize the distribution of fibers and fillers in the matrix, as well as to assess the composite's endurance under various environmental conditions.

3.4. SEM Analysis

The microstructure of composite fractures following impact testing was investigated using scanning electron microscopy (SEM). In the case of sample X10/5 (Figure 8a), the contact area between the fiber and matrix is reduced due to the distance between them. Composites are more prone to structural damage such as cracking, fracture, or delamination under impact loading as a result of this, as the interaction strength between the fiber and polyester decreases and load transfer efficiency decreases. The fracture morphology of the X30/5 composite is depicted

in Figure 8b, in contrast. The polymer matrix exhibits a uniform distribution of fibers as seen in SEM pictures. The large concentration of these fibers may make them look more dominant in the fracture morphology. The composite's impact strength may be increased by this equal distribution of fibers, which facilitates effective load transfer during the application of impact force. Furthermore, it was shown that there were greater and denser connections between the fibers and matrix in the fracture morphology. Interfacial adhesion contributes to the greater toughness of the composite by facilitating the transmission of stress from the matrix to the fiber [25,26]. The low amount of space between the fiber and the polyester matrix is further demonstrated in Figure 8b. Despite the high DP concentration, the production of a tiny space between the fiber and the matrix in the fracture morphology is believed to be caused by the low concentration of rice husk filler (5%). As a result of the fibers and filler being firmly bonded together within the matrix, there is less chance of structural failure from extra space and effective load transfer. This explains the relatively high impact strength of the X30/5 sample.

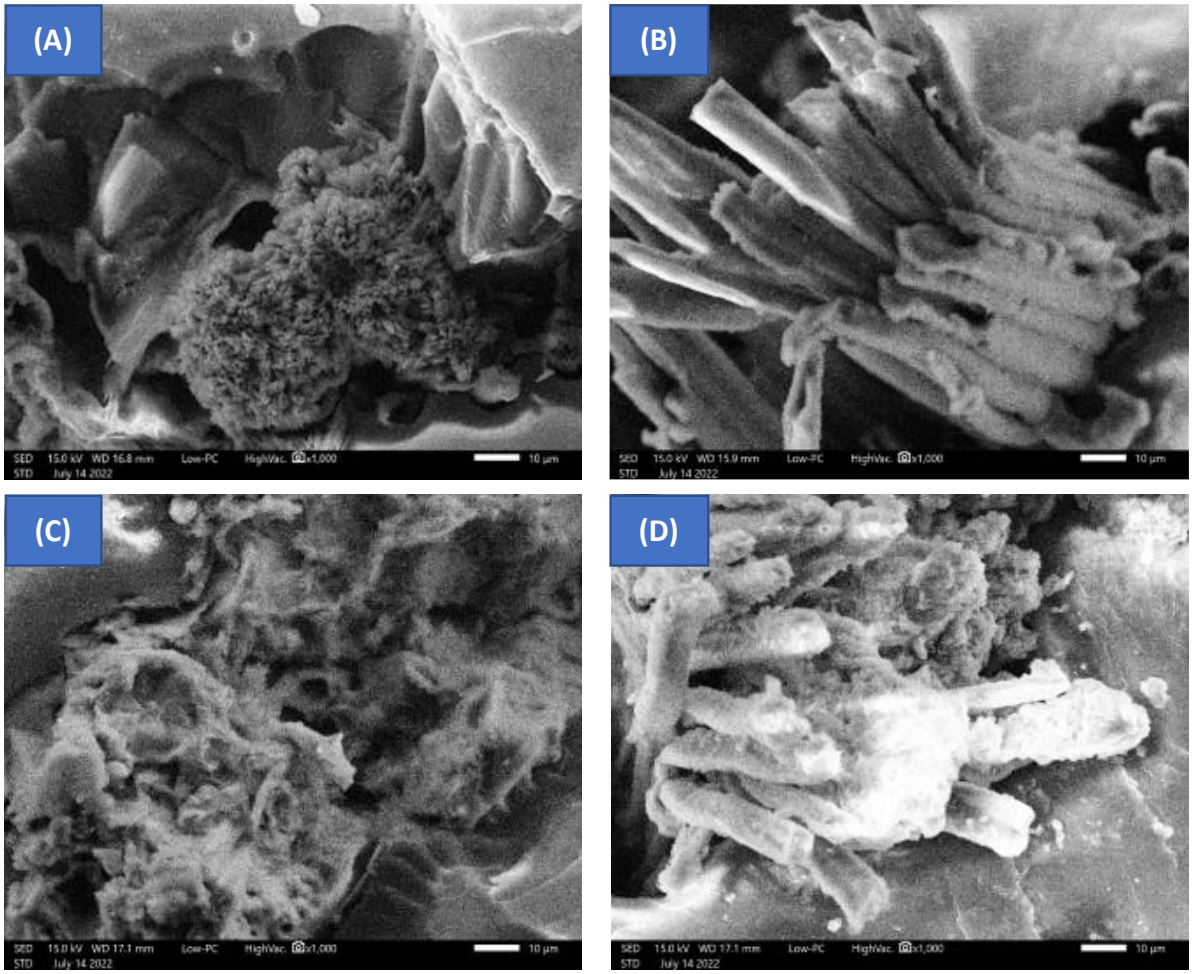

Fig. 8. SEM images of composites, (a) X10/5, (b) X30/5, (c) G10/10, and (d) G30/10.

Because DPs are comparatively less concentrated than RH filler, Figure 8c shows the uneven distribution of fiber in the matrix. Furthermore, the SEM images display regions exhibiting heterogeneous cracks, apertures, or brittle patches. These features are assumed to lead to a reduction in the overall strength and structural coherence of the composite; they also suggest inefficient load transfer and inadequate matrix adhesiveness [27–29]. It seems that the G10/10 composite structure is more dominated by the amount of RHs filler than by fiber. This dominant filler can cause porosity and empty spaces to build in the composite structure. Additionally, because it contributes less to the composite's strength against impact pressures than fiber does, the impact strength that results from this filler is relatively low. The G30/10 sample, which has a uniform distribution of fibers, a high fiber-matrix contact strength, and blockage of the gap between fibers and matrix, is shown in SEM pictures in Figure 8d. The fracture

morphology of the composite, which has a high concentration of pandan fiber (30%), demonstrates the existence of equally distributed fibers in the polyester matrix. The strength and longevity of the composite can be increased by this equal distribution of fibers, which facilitates effective load transfer during impact force application [29, 30]. Furthermore, the presence of fiber drag by the matrix is depicted in Fig. 8d, indicating that the fiber can transfer loads well and successfully preserve its structural integrity [31,32], leading to high strength. The high fiber concentration may also assist fill most of the space between the fiber and the matrix, even with the 10% rice husk filler, therefore reducing the amount of space that could weaken the composite structure and increase the composite strength.

4. Conclusions

The study successfully investigated the impact strength and thermal resistance of RHs-filled DPs-reinforced polyester composites. The findings demonstrate that increasing the DP content enhances both the impact strength and thermal characteristics of the composites. Specifically, sample G30/10 exhibited the highest impact strength at 55.8 ± 1.89 KJ/mm^2, while sample X10/5 had the lowest at 22.23 ± 3.4 KJ/mm^2. The thermal stability of the composites was also influenced by fiber and filler content, with sample X30/5 showing the highest thermal stability. SEM analysis revealed that fiber distribution, cracks, and voids between the fibers and matrix played a significant role in the composite's mechanical performance. The high fiber concentration contributed to filling gaps in the matrix, which in turn improved the structural integrity and overall strength of the composites. These findings suggest that composites reinforced with DPs and RHs have considerable potential for usage in applications that need high mechanical strength and thermal resistance. Potential uses include the automobile industry, construction materials, and green thermal insulation solutions. This composite's lightweight, renewable, and low-cost properties make it an appealing option to synthetic yarn or wood-based materials.

Future research should focus on optimizing the interface between the fiber and the matrix to minimize voids and enhance load transfer. Exploring alternative surface treatments for the fibers may improve adhesion and overall composite performance.

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Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

Availability of Data and Materials

All data are available from the authors.

Author Contributions

Nasmi Herlina Sari: Writing – original draft, Investigation, Data curation.
Suteja, Sujita, Dicky Hartawan Dwitama: Investigation, Writing – review & editing, Supervision, Project administration. Sanjay Mavinkere
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